Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Exploring the Potential of Computational Fluid Dynamics in Indoor UV-Assisted Air treatment

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ABSTRACT

Indoor Air Quality (IAQ) is of essential importance and usually has a long-term effect on health; unlike infectious disease, which would be an immediate threat to humans. Then, reducing airborne pathogens in occupied indoor environments becomes necessary and ultraviolet-C irradiation at 222nm has shown potential to tackle the problem. This study presents a computational fluid dynamics (CFD) investigation into pathogen disinfection within a room equipped with a Far-UVC light source operating at 222 nm. Employing a two-phase flow system within an Eulerian-Lagrangian framework, the simulation captured both the flow field and discrete pathogen particles, with interactions modelled in a one-way coupled manner. The radiation field was simulated using the Discrete Ordinates (DO) Radiation model theory, enabling accurate prediction of the fluence rate throughout the indoor environment.

To assess the disinfection performance, a user-defined function (UDF) was developed to calculate the dose absorbed by each pathogen particle as they travel through the irradiated space. This approach facilitated a detailed analysis of the dose-response behavior under varying conditions. Validation of the CFD model was achieved by comparing experimental measurements of both fluence and pathogen dose-response, ensuring the reliability of the simulation results.

Furthermore, the study explored the impact of the pathogen introduction point on disinfection efficacy. By systematically varying the introduction locations by providing insights into how spatial factors influence the interaction between airflow, UV irradiation, and pathogen exposure. The findings indicate that the positioning of pathogen sources relative to the Far-UVC light or the inlet vents significantly affects the absorbed dose, and thus the overall disinfection efficacy.

The integration of CFD with radiation modelling and post-processed dose calculation offers a robust framework for optimizing indoor disinfection strategies using Far-UVC technology. This work contributes to a deeper understanding of the dynamic interplay between fluid flow, UV radiation, and pathogen inactivation, and holds promises for improving the design and implementation of disinfection systems not only in public and healthcare settings but in the research stage where the design of reliable experiments is important.